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Development of Data Processing and Analysis Tools for Atmospheric Radiation Measurements

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Abstract

This paper reports on the data processing methods and techniques of measurements, made by several miniature radiation spectrometers flying on different types of carriers within the Earth's atmosphere at aviation and balloon altitudes.

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1. Introduction

The Earth is continually being hit by very high-energy charged particles, called galactic cosmic rays (GCR), coming from outside the solar system. It also receives, during a solar event, such particles from the Sun. With their high energies these particles are able to penetrate the magnetic field lines of the Earth and reach its upper atmosphere. There they collide with its constituents and by nuclear interactions generate a shower of daughter products such as protons, muons, neutrons, heavy ions, etc. If they have sufficient energy, these daughter products can also, by collision, create other particles. This results in a cascade of secondary particles inside the atmosphere. Many of the charged particles have a small mean free path and are very quickly "absorbed." Neutrons, due to their neutrality, can penetrate further into the atmosphere. A competition, then, exists between the various production and removal processes. The result is a maximum in the radiation flux at about 60000 ft [1]. At aviation altitudes (about 30-40 kft), neutrons are the main constituents of the natural radiative environment. They are responsible for the total dose received by the airplane's crew and are correlated to the single event effects in aircraft electronics [1]. The distribution of these secondary particles is still not very well known and depends on several factors. The altitude or the atmospheric depth is one of these factors. At low altitude the density of the atmosphere is greater than at high altitude, and phenomena of absorption and diffusion are more important and the number of cosmic-ray secondaries is reduced. Cosmic rays are charged particles and are influenced by the Earth's and the Sun's magnetic field. For example, cosmic rays have a greater ability to reach Earth's magnetic poles where field lines are open, than the equator. The best way to describe their distribution is to use the Earth magnetic field strength B and the McIlwain magnetic shell parameter L. These two parameters will correspond to the latitude and longitude variations in geographic coordinates. Cosmic rays are also influenced by the solar activity and space weather conditions and especially by the intensity of the solar magnetic field that acts like a moderator.

The goal of this study is to develop the tools to process data collected with different radiation spectrometers placed on several carriers as airplanes, balloons, etc. By knowing the position of the carrier for the duration of each flight, the measurements may be used to create a large enough database over time to be statistically significant in order to develop a global mapping of cosmic-ray secondaries, particularly neutrons, defining their intensity at a specific location.

2. Instruments and Measurements

A description of the radiation spectrometers is given in [2]. The LIULIN instruments are placed on different carriers like commercial airplanes, piloted or unpiloted special aircraft, and high-altitude balloons, for several weeks at a time and can accommodate dozens of flights. After a mission, the collected data are downloaded on a computer as a data file containing the date and the time of each measurement and the number of counts by channel, recorded by the analog to digital converter, corresponding to the deposited energy by the particles. For each mission several locations of the carrier are known. They can have the form of GPS generated computer files for balloons or of flight plans for special aircraft and commercial airplanes. Measurements are usually made every 5 min but can be obtained at other intervals ranging from 10 sec to 30 min.

3. Data processing

TIME SHIFT

By inspecting the data, it was noticed that the time recorded inside the flash memory and downloaded into the computer was not in accordance with the real time. The problem comes from the instrument's associated electronics. Instead of recording the data every five min, a shift of several millisec per measurement exists. It means that inside the data file the time step is five min while in reality this step is more or less than that. This shift can amount to a difference of more than 10 min for records at the end of a 21-day mission. It is corrected by comparing the time of the last instrument blink (each time a spectrum is recorded inside the flash memory a red light on the top of the instrument blinks) with the last time recorded inside the data file. The difference between these two times divided by the number of records gives the time shift per record. The data processing program developed in-house can then correct the shift. After this process, the real date and time are known for each record of the mission.

FLIGHT PLAN

Unlike special airplanes, the flight plan for commercial airlines is not provided as a GPS-generated computer file. For these kinds of flights the plan is preprinted on a sheet several hours before departure with a predetermined schedule and route. It contains the estimated passage time for several flight control locations and it has to be entered by hand into a computer. A special software package was developed for the purpose of allowing to see the flight route on a 2-D map. Figure 1 shows one of these routes. Unfortunately, the schedule and the route are very often changed. The plane can be delayed and the flight plan is then not updated; the plane can also encounter a storm during its flight forcing the pilot to change his route. The corrections are usually made by the pilot on the printed flight plan. Sometimes, however, the time corrections are not made at all and the locations of the plane for a certain time are wrong. Using the LIULIN data files can solve this problem. An increase in the number of counts caused by the greater number of particles at higher altitude should be seen just after take-off. If the increase of the counts occurred before or a long time after the estimated take-off time printed on the flight plan it means that the plane was delayed or took off earlier. Flight times can then be shifted for matching with the LIULIN file. Figure 2 shows one example of matching.

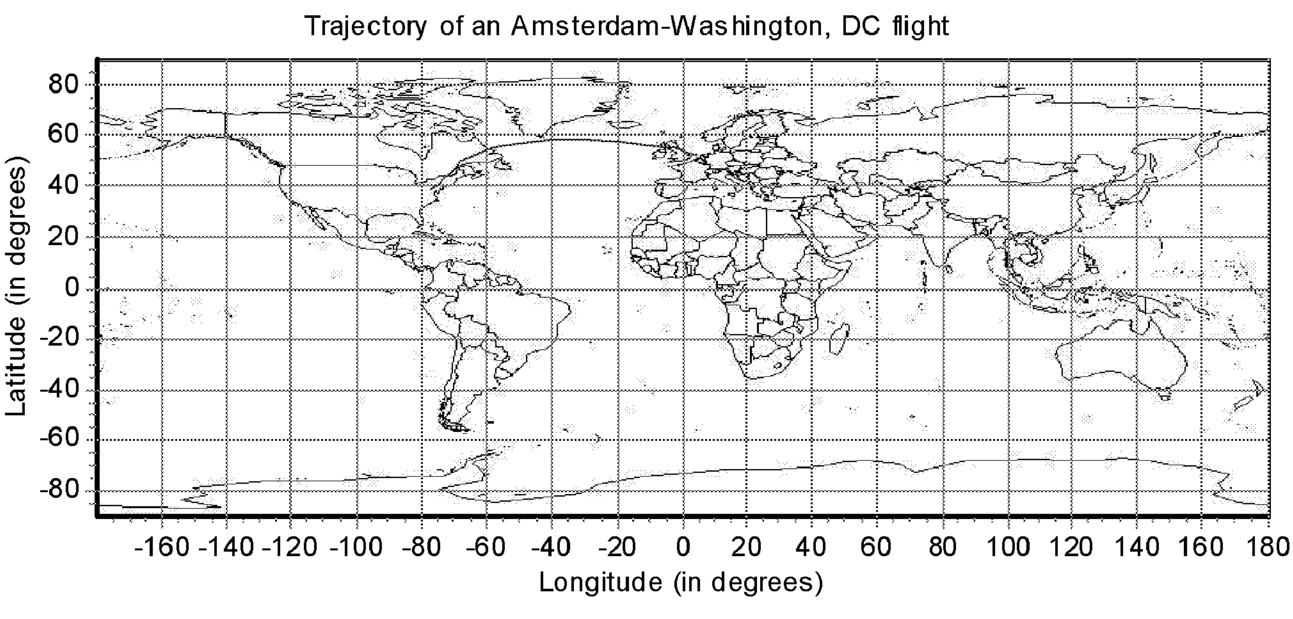

Figure 1. Trajectory of a typical commercial flight between Amsterdam, NL, and Washington, DC, in March 2001. It shows the airplane almost reaching Greenland before heading to Washington, DC.

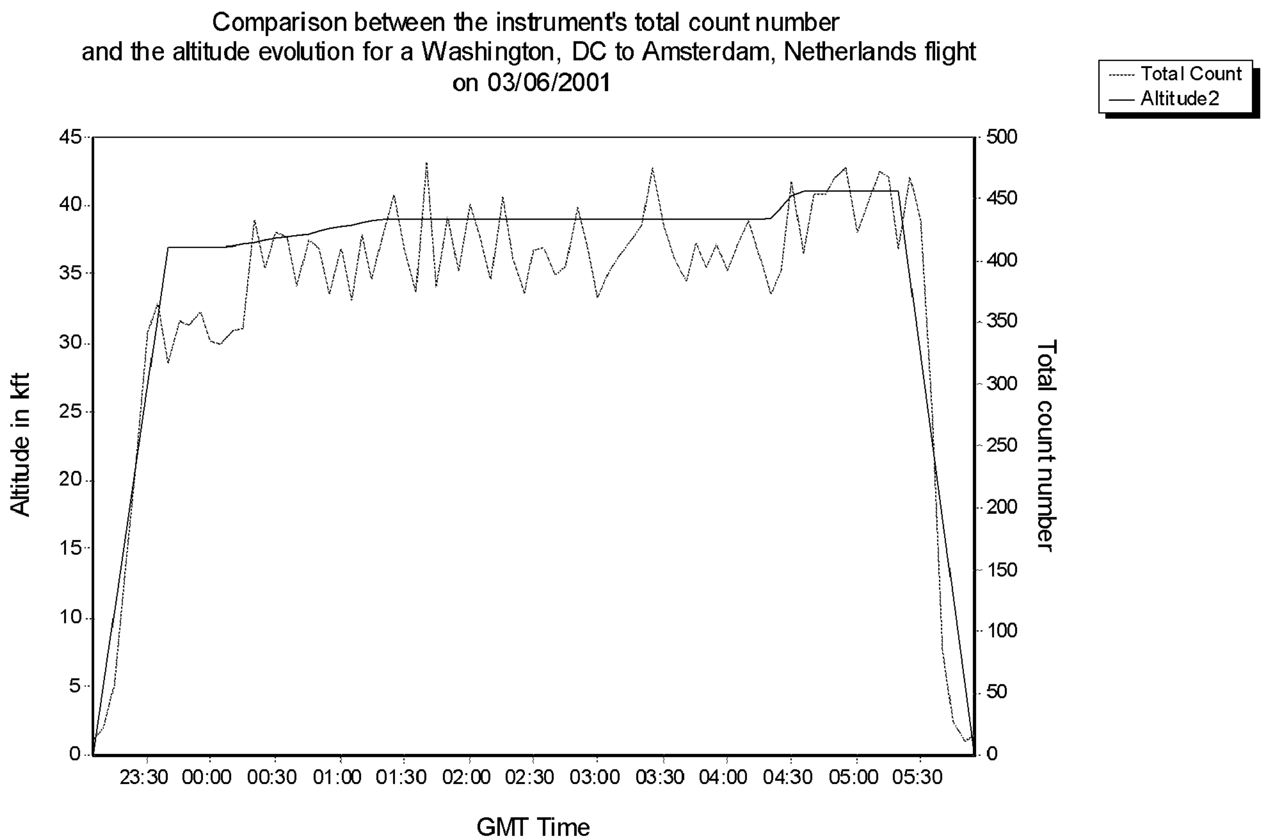

Figure 2. Representation of the evolution of the altitude of the flight and the number of counts in the detector for the same period of time. If these evolutions do not match it means that the times of flight plan are wrong and need to be shifted (not the case here).

EXTRACTING FLIGHTS

The file downloaded from the instrument's flash memory contains data for several flights and data when no flight occurred. The next step is to separate each flight into a specific file that will contain the data, the coordinates, and the date which requires that the data from the instrument be combined with the positional information from the flight plans.

Thus, once a flight plan is processed, it can be associated with the LIULIN data. However, time intervals between two locations provided in the flight plan are very often greater than the LIULIN measurement interval (5 min) and coordinates of each record need to be calculated by making an interpolation between the last known location before the record and the first known location after the record. These coordinates are then matched with the LIULIN data and saved in a database master file. This file contains for each record the number of counts in each channel, the number of channels with data, the exact time, and the geographic (latitude, longitude, altitude) coordinates. With the date and the coordinates the value of the magnetic parameters B and L can be calculated and the solar conditions (magnetic storms, etc.) can be determined for the period of the flight. Every flight extracted from the LIULIN data file has a specifying filename. Four characters of this filename identify the type of the detector, four for the type of carrier (commercial airplanes, balloon); the last characters are the date and time of the first record inside the file. This specific file name allows grouping the flights by date or type of carrier and/or detector.

CALCULATIONS

Another software can read the database for specific flights to calculate and plot the dose for each record and different groups of channels representing different dose ranges [2]. The spectrum for one or several records can also be determined.

4. Results

Three flights are presented here from data collected on commercial airlines every five min. Other data are being or were previously [2] analyzed to create a large database. Figure 3 is a plot of dose rate versus time for a flight between Hong Kong and Hokkaido Island, Japan; Figure 4 is the trip Los Angeles-Honolulu and Figure 5 Sydney-Jakarta. Flight plans for these data are used to provide positional coordinates of each for further analysis.

5. Discussion

For all flights in the following figures the dose is a function of altitude and magnetic latitude. The dose can reach 0.2 microgray by 5 min. The flight between Hong Kong and the Hokkaido Island is particularly interesting because according to flight plan it happened at a constant altitude and we can see the influence of the geomagnetic latitude. The dose increases as the flight approaches Japan. It can be explained by the fact that in Hong Kong we are closer to the magnetic equator than in Hokkaido and only very high-energy cosmic rays can reach these regions. As a consequence, we have less secondary products and the dose is lower than in higher latitudes where cosmic rays have a greater ability to penetrate the magnetic field lines.

The flight between Los Angeles and Honolulu shows the combined effects of the altitude and the geomagnetic latitude. The first part of the flight occurred at 33000 ft and we can see the dose decreasing due to the fact that the plane is heading to lower latitudes. Around 15h15 GMT we can see the dose increases. It is at this time that the plane changed altitude from 33000 ft to 35000 ft. We can see here the effect of the altitude on the dose received by the crew. The higher you get in altitude, the higher the dose received. Then the dose decreases again as the flight is heading to lower latitudes for landing.

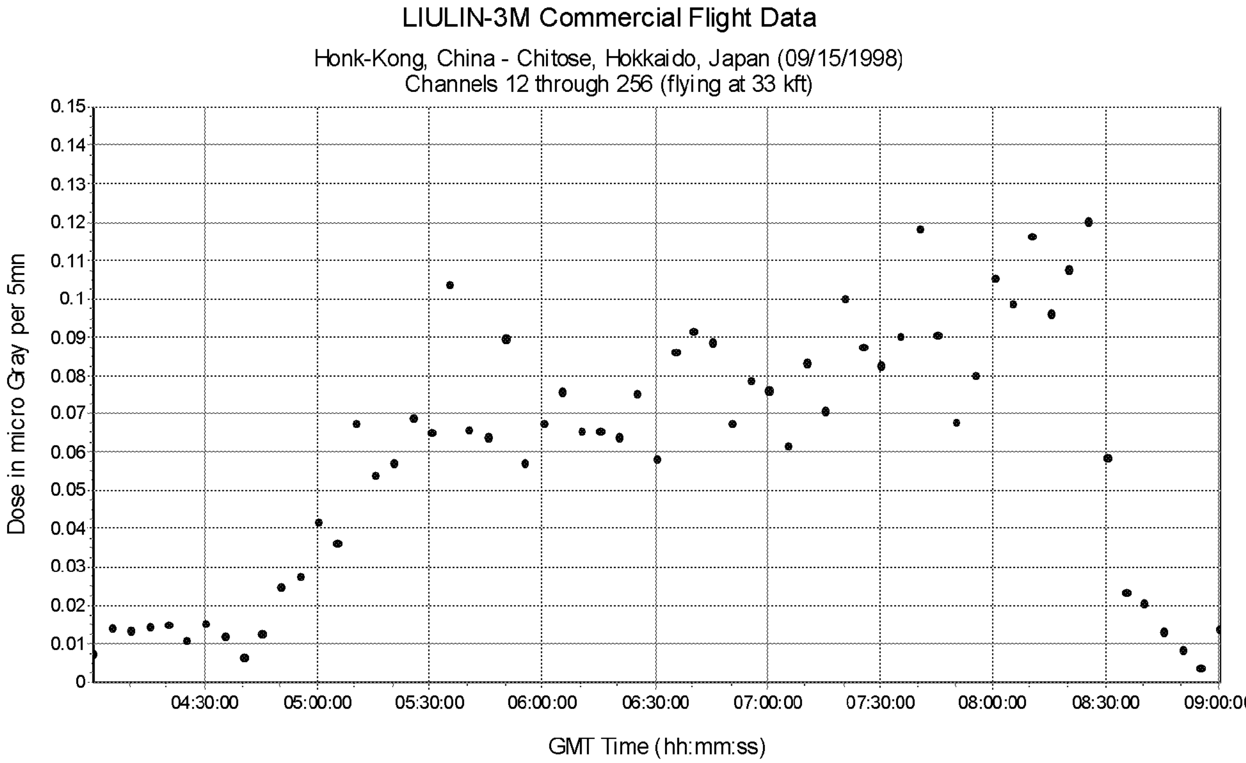

Figure 3. Dose plot of the Hong Kong-Hokkaido flight.

The trip from Sydney to Jakarta confirms the effect of geomagnetic latitude. This time we can see a decrease of the dose as the flight approaches Jakarta. The explanation is the same as for the previous flight: Jakarta is closer to the equator and there are less secondaries than in Sydney, situated at higher latitude.

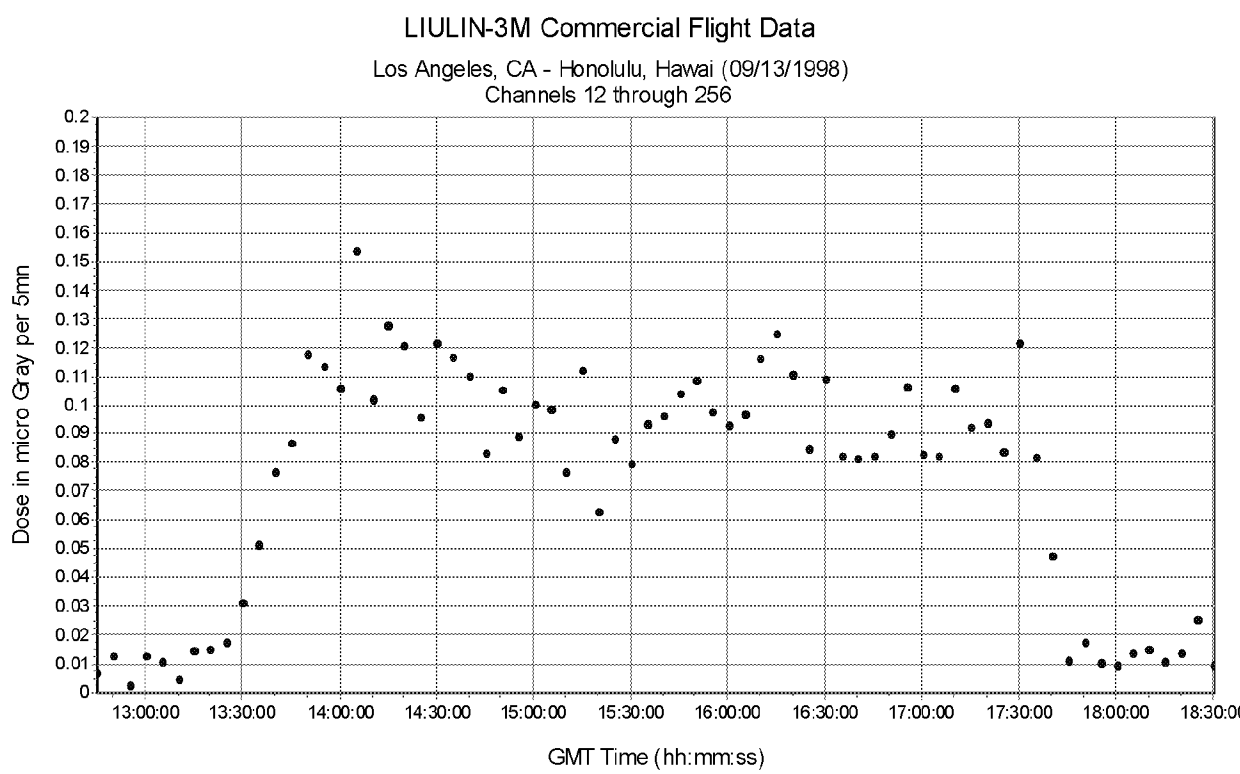

Figure 4. Dose plot for the Los Angeles-Honolulu flight.

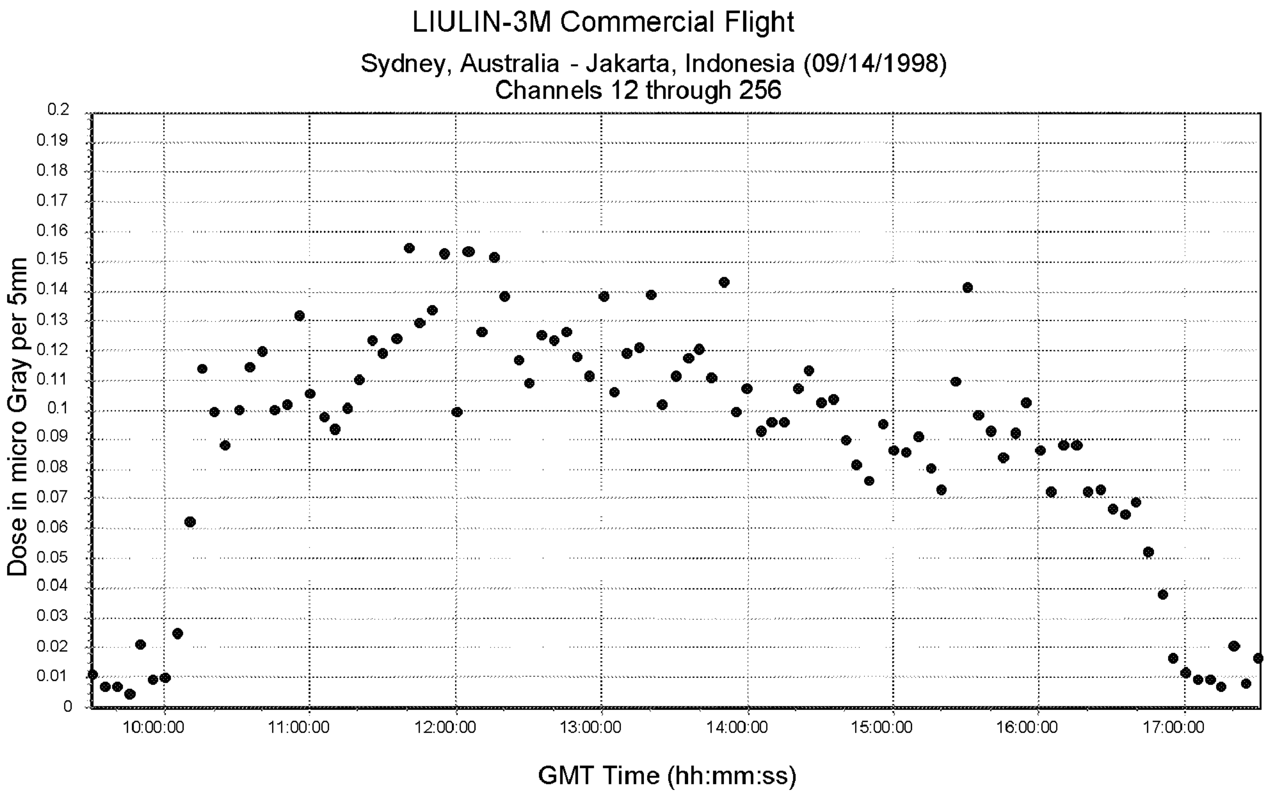

Figure 5. Dose plot for the Sydney-Jakarta flight.

Conclusion

In these three flights one can see the importance of the location for radiation levels received by airplane electronics and crew. This analysis is currently limited to regular avionic altitudes (30 kft-40 kft). But very soon some flights made with high-altitude balloons and aircraft will provide valuable data at levels of greatest radiation intensity (55 kft-65 kft). Instruments will also be flown on the French Concorde, which flies at higher altitude than other passenger airliners. Data collected over long periods of time may also show the influence of solar cycles and conditions.

The analysis tools will also be improved in order to have the most accurate data possible in terms of geographic locations (flight plans analysis) and an interactive access to the large database will be developed.

References

[1] A.Taber and E. Normand, “Single event upset in avionics,” IEEE Trans. Nucl. Sci., vol. 40, p. 120, 1993.

[2] E.G. Stassinopoulos et al. “Measurements of radiation exposure on commercial aircraft with the LIULIN-3M instrument,” to be published 2001.

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This paper reports on the data processing methods and techniques of measurements, made by several miniature radiation spectrometers flying on different types of carriers within the Earth's atmosphere at aviation and balloon altitudes.

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